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A human observer can sometimes choose to ignore almost all the information impinging on the sense organs and select only one or two relevant items. At other times information simultaneously available from several stimulus sources must be combined. An example is piloting an aircraft under combat conditions. We have been investigation how skilled observers divide attention and testing models that explain their performance. Our work has addressed two related issues: (1) When an observer must decide whether a target has been presented in any of several channels - i.e. under conditions of divided attention - how does he or she combine information from the set of channels? (2) Under what conditions does an increase in the number sources over which attention is divided require that less information be extracted form each source? In earlier work we sought to answe these questions for three types of visual stimuli and for simple bimodal stimuli. More recently we have investig-ted division of attention in audition. We carried out two sets of experiments using brief tone bursts embedded in white noise. Because frequency bands are often regarded as independent information channels,

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we designed the first set to discover how subjects combine information about two frequencies in deciding whether either of two tones has been presented. We varied frequency separation over a wide range to insure that some tone pairs fell within the same hypothetical channel whicle others fell into distinct channels. Results support two principal conclusions: first , with separated frequencies the combination rule appears to be under the subjects control rather than being a property of the auditory system. Second, under conditions of frequency uncertainty subjects usually arrive at their yes/no response by combining separate decisions about the presence of each frequency. Only when the two frequencies were very close did our findings under frequency uncertainty support the classic signal detection model in which information form the two channels is integrated to form a single decision variable.

In a second set of experiments we investigated the consequences for tone identification and forcedchoice detection of increasing the number of frequency channels across which attention must be divided. We found no evidence for information loss when the number of possible tones was increased from 2 to 4, and thus no evidence thatthat monitoring multiple frequency channels is a capacity-limited task.

ATTENTION AND DECISION IN AUDITORY INFORMATION PROCESSING

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A human observer can sometimes choose to ignore almost all the information impinging on the sense organs and select only one or two relevant items. At other times information simultaneously available from several stimulus sources must be combined. An example is piloting an aircraft under combat conditions. We have been investigating how skilled observers divide attention and testing models that explain their performance. Our work has addressed two related issues: (1) When an observer must decide whether a target has been presented in any of several channels - i.e. under conditions of divided attention - how does he or she combine information from the set of channels? (2) Under what conditions does an increase in the number sources over which attention is divided require that less information be extracted from each source?

In earlier work we sought to answer these questions for three types of visual stimuli and for simple bimodal stimuli. More recently we have investigated division of attention in audition. We carried out two sets of experiments using brief tone bursts embedded in white noise. Because frequency bands are often regarded as independent information channels, we designed the first set to discover how subjects combine information about two frequencies in deciding whether either of two tones has been presented. We varied frequency separation over a wide range, to insure that some tone pairs fell within the same hypothetical channel while others fell into distinct channels. Results support two principal conclusions: First, with separated frequencies the combination rule appears to be under the subject's control rather than being a property of the auditory system. Second, under conditions of frequency uncertainty, subjects usually arrive at their yes/no response by combining separate decisions about the presence of each frequency. Only when the two frequencies were very close did our findings under frequency uncertainty support the classic signal detection model in which information from the two channels is integrated to form a single decision variable.

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A Gating Model of Shifts of Visual Attention

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This project is being carried out jointly with Adam Reeves. The aim of the research is to determine the nature of the cognitive processes involved in brief acts of attention. For example, when an observer shifts his attention from point A to point B in the visual field, what is the first thing he sees at point B? How do subsequent events at point B interfere with his memory of the first event? When events occur at B too rapidly to be perfectly processed, is it possible to construct a mathematical theory to predict precisely what events will be remembered and how accurately?

To answer these questions, a laboratory situation was contrived in which events are easily labeled (brief flashes of numerals, one on top of the other) so that their fate in memory can be conveniently determined. Specifically, the empirical data are derived from an experiment in which an observer maintains stable eye fixation but shifts his attention from a location where a target is presented to a location where a stream of numerals is presented, each numeral superimposed upon the previous one. The task is to report the earliest occurring numeral (or, in some conditions, four numerals) after target detection. The data consist of $P_i(r)$, the probability of a numeral from stimulus position i appearing in response position r, and P_{iBj}, the probability that a numeral from stimulus position i is written *before* (earlier in the response than) a numeral from stimulus position j.

For all subjects, targets, and numeral rates, the relative positions of numerals in the response sequence showed *clustering, disorder*, and *folding*. Reported numerals tended to cluster around a stimulus position 400 msec after the target. The numerals were reported in an apparently haphazard order —at high numeral rates, inverted iBj pairs were as frequent as correct pairs. The actual order of report resulted from a mixture of correctly ordered numerals with numerals ordered in the direction opposite to their order of presentation (folding around the cluster center).

The use of pairs of numerals to analyze recall order is novel and allows the full power of psychometric methods developed for pair comparisons to come into play. Thereby it is proved that the data are describable by a strength model, and a particular instantiation, a gating model is proposed. The *gating* model of attention assumes that with delay $\tau \approx 250$ *msec* after target detection, an attentional gate opens to [illegible] information from the numeral stream into memory. The temporal course of gate [illegible]ing $a(t)$ is well-described by a gamma function $a(t)=(t-\tau)\alpha^{-2}e^{(t-\tau)/\alpha}$, which is derived [illegible] a general attentional model *in which order relations are accounted for by lateral* inhibitory interactions in memory. The attention gating model is an extremely efficient computational mechanism: for each subject, it uses only 2 attentional and 3 to 6 detection parameters to predict 85% to 90% of the variance in over 500 values of $P_i(r)$ and P_{iBj} in 12 experimental conditions.

The gating model is formally equivalent to a more easily visualized "snapshot" model in which an act of attention consists of taking a snapshot (a photograph) of the stimulus events with a shutter having a delay of about 250 msec and an exposure duration of about 150 msec (typical value of α). All subsequent responses (including those involving sequential order relations) are constructed from what appears in the attentional snapshot, and this accounts for the clustering, disorder, and folding in the data —the illusory as well as the correct reconstructions of events.